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COMPOSITE PANELS OF COLD-FORMED STEEL AND TIMBER FOR HIGH-DENSITY CONSTRUCTION

Pinelopi Kyvelou¹, Thomas Reynolds², Chris Beckett², Pui Wah Wong², Yuner Huang²

ABSTRACT: Timber and cold-formed steel are primary materials in the construction of temporary, emergency and informal settlements worldwide. This is because these materials are widely available, can be cut and fixed with hand tools and their light weight makes them easily transportable and manually erectable. However, construction with a single skin of cold-formed steel can often lead to a building which is structurally, thermally and acoustically unsound. A composite panel of oriented strand boards and cold-formed steel sheeting is proposed herein, the overall structural behaviour of which is investigated. Based on experimental results obtained from push-out and flexural tests, the mechanical properties of the employed connectors are determined while the predominant failure modes are highlighted. The feasibility of mobilising composite action between the components of the proposed system is proven while the corresponding derived benefits, both in terms of load carrying capacity and stiffness are quantified. The overall structural performance of the proposed composite panel is shown to substantially improve through harnessing the beneficial influence of composite action, offering the potential to significantly ameliorate the quality of housing in informal developments and rapidly urbanising areas.

KEYWORDS: Cold-formed steel, composite panels, self-drilling screws, oriented strand boards, push-out tests, structural efficiency

1 INTRODUCTION

In this paper, a lightweight composite system comprising cold-formed steel and timber is proposed for the construction of panels for low-rise multi-storey buildings within the framework of a rapidly urbanising society. Bangladesh, Malaysia and North-East India, used as case study regions for the proposed technology, are subject to tropical cyclones, flooding and earthquakes; hence the resilience of any proposed form of construction to these events is critical. Structural elements of low mass are beneficial in terms of earthquake resistance due to reduced inertia forces acting on the structure, while resistance to uplift loading due to high wind loads can be ensured through large panels, tied down to the vertical structural components at dense intervals. Ultimately, when panelised construction of low mass is combined with the use of locally-available materials, rapid, economical and efficient post-disaster construction can be achieved.

The structural system proposed herein comprises materials that can be easily found in the examined regions: cold-formed steel (CFS) sheeting, which is already widely used for roofing and cladding [1], and

oriented strand board (OSB) panels. Within the framework of the proposed system, these materials are multi-functional as they can act as structural components, resulting in increased stiffness and load carrying capacity, and also provide both thermal and sound insulation as well as damping capacity, leading to reduced heat loss, sound transmission and vibrations, respectively. Finally, the OSB panels, being fabricated from strands of timber, can be manufactured from the smaller pieces of wood produced by small-scale agroforestry. Encouraging the use of this resource may also yield economic and environmental benefits in the overall region [2].

Since, for the reasons mentioned above, the combination of two different materials (namely CFS and OSB panels) is proposed, there is potential for even further benefits to be gained if composite action arises between the employed components of the proposed structural system. A substantial shear connection at the CFS-OSB is required for this scenario to be realised.

Recent research has shown that the mobilisation of composite behaviour is feasible within systems employing materials similar to those proposed herein, leading to substantial benefits in terms of load carrying capacity and flexural stiffness [3,4]. Thus, the project will explore the potential of maximising the structural efficiency of the proposed panels by exploiting the beneficial influence of composite action between the structural components.

2 MATERIALS AND METHODS

When selecting the structural components of the proposed composite panel, the main focus was the identification of economical, easily available and

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lightweight materials in order to facilitate rapid assembly on site. Thus, the proposed panel system, a typical example of which is illustrated in Figure 1, comprises CFS sheeting connected to OSB panels by self-drilling screws at 100 mm spacings along the ribs of the steel sheet. Self-drilling screws were chosen as shear connectors as they can be installed with hand tools and are the most frequently employed type of fasteners currently used in industry to connect cold-formed steel and timber products.

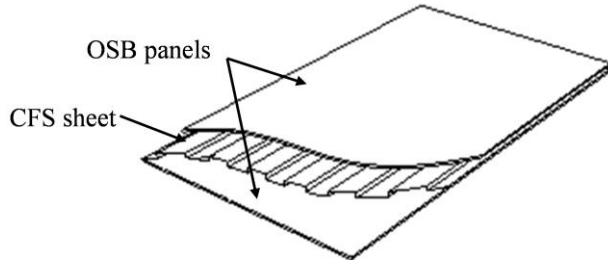
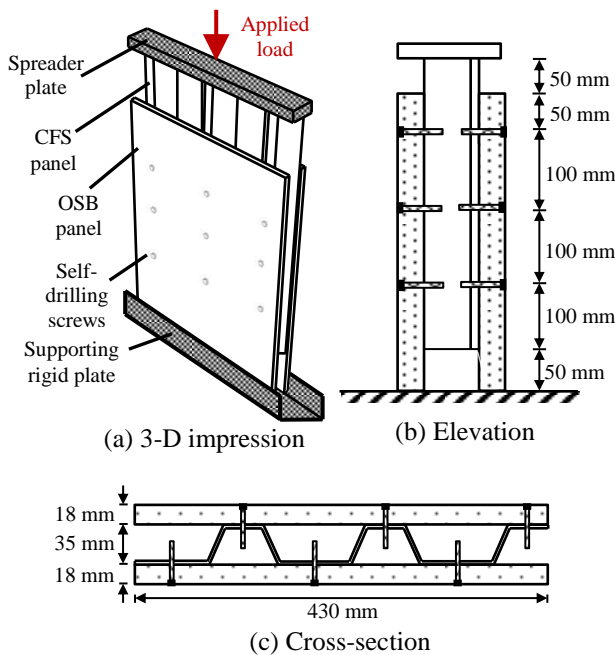


Figure 1: Illustration of the proposed panel system

Since the proposed system is, for the first time, introduced herein, no relevant experimental data exist in the literature. Hence, an experimental programme comprising push-out and flexural tests was carried out to investigate the structural performance of the proposed composite panels.

2.1 Push-out tests

Push-out tests were carried out to investigate the load-slip response of the employed shear connectors. Each specimen comprised two OSB panels, one on each side of a CFS panel, with self-drilling screws at a constant spacing of 100 mm installed along the panel ridgelines; a typical specimen is shown in Figure 2.



(d) Photograph

Figure 2: Typical (a) 3-D impression, (b) elevation, (c) cross-section and (d) photograph of push-out specimens

In line with EN 383 [5], each specimen was subjected to an initial loading cycle up to 40% of the expected ultimate load carrying capacity P_{max} of the system, then decreased to 10% of P_{max} , and then increased again, up to failure, with a constant loading rate of 2mm/min, chosen to ensure occurrence of failure at approximately 5 minutes.

2.2 Flexural tests

Following completion of the push-out tests, flexural tests on full-scale panels were performed to examine the overall structural behaviour of the proposed composite system.

The tested composite specimen comprised two OSB boards, one on top and one at the bottom of a CFS panel, both fastened with self-drilling screws at standard intervals of 100 mm (specimen F_3).

Bare steel and OSB panels (specimens F_1 and F_2 , respectively) were also tested to provide a benchmark response for the rest of the specimens. A summary of the tested specimens is presented in Table 1.

Table 1: Description of tested flexural specimens

Specimen	Description	Connectors
F_1	Bare CFS	NA
F_2	Bare OSB	NA
F_3	OSB-CFS-OSB	Self-drilling screws

All specimens were simply supported on rollers and subjected to four-point bending. Two steel tubes, loaded by a spreader beam, were employed for distributing the load along the width of each specimen, at the positions of point loads. Due to the slender nature of the CFS panel making it prone to local instabilities, and in line with EN 1993-1-3 [6], the cross-sections of the specimens located at the positions of point loads and at the supports were locally strengthened with timber blocks to prevent premature localised failure of the CFS panel. A typical strengthened cross-section is shown in Figure 3.

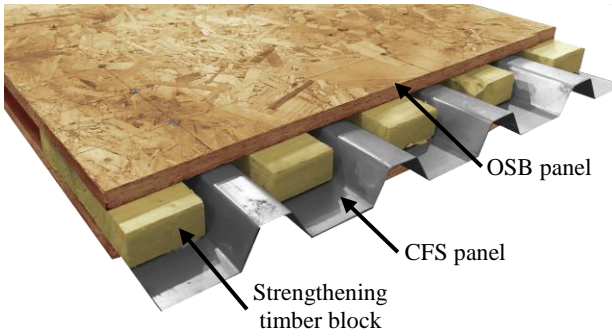
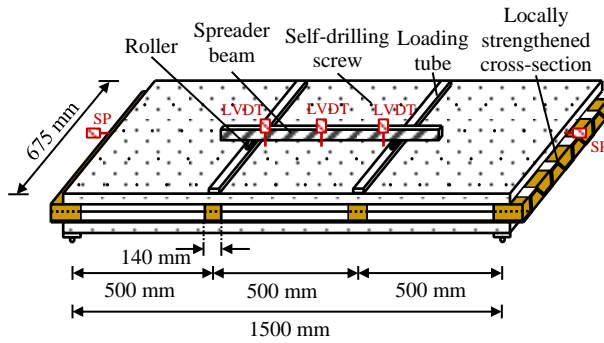
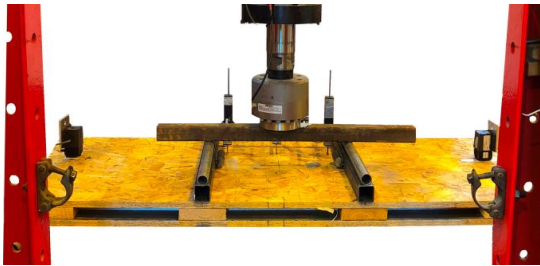


Figure 3: Strengthened cross-section at the positions of point loads and supports

Vertical deflections at the positions of point loads and at midspan were measured by linear variable displacement transducers (LVDTs) while horizontal slip at the CFS-OSB interface was also recorded at both ends of the composite panel with string potentiometers (SPs). The employed experimental setup, adapted from [3], is presented in Figure 4 while the cross-section of the tested composite panel is shown in Figure 5.



(a) Schematic illustration



(b) Photograph

Figure 4: (a) Schematic illustration and (b) photograph of experimental layout and instrumentation of flexural tests

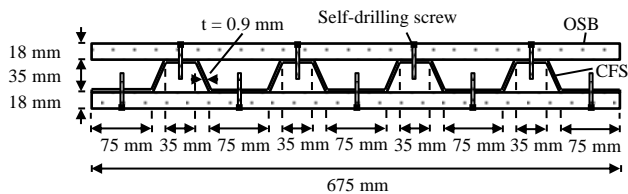


Figure 5: Cross-section of composite panel

All specimens were subjected to an initial loading cycle of up to approximately 25% of their peak load to ensure proper positioning of the specimen within the test setup and correct function of the measuring instrumentation. Following this initial cycle, all specimens were loaded until failure at a constant displacement rate of 2 mm/min. Note that the moisture content of three samples of OSB was measured by the oven dry method [7], giving a mean moisture content of 7.3%.

3 RESULTS AND DISCUSSION

3.1 Results of push-out tests

As expected, all push-out specimens exhibited similar behaviour; their load-slip responses are shown in Figure 6.

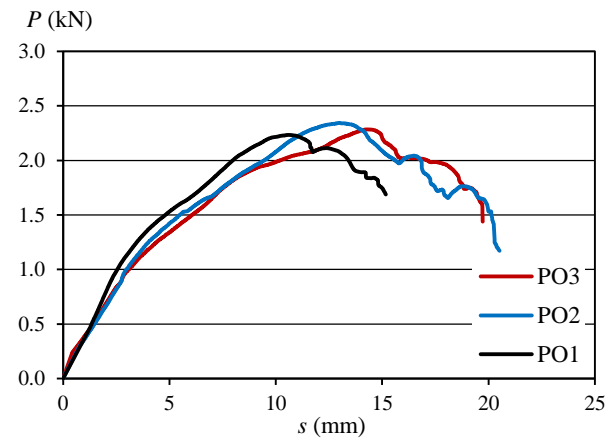


Figure 6: Load-slip responses of push-out tests

The observed failure mode at peak load for all specimens corresponded to shear failure of the connection. However, significant bearing of the screws into the OSB panels had occurred prior to attainment of the peak load. A typical push-out specimen after failure is presented in Figure 7, showing the deformed connectors.

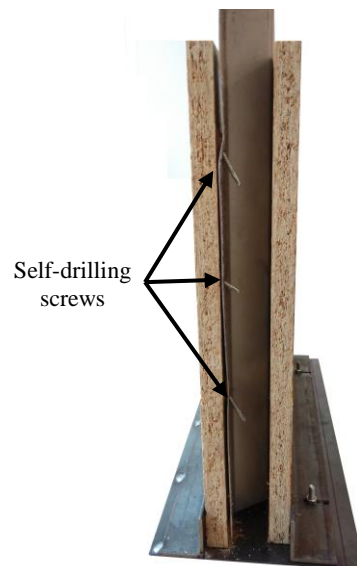


Figure 7: Typical push-out specimen after failure

In line with [8], the ductility of the connection D for each specimen was calculated according to Equation (1):

$$D = \frac{V_u}{V_y} \quad (1)$$

where V_u and V_y are the ultimate and yield slips, respectively, as defined in [8]. A summary of the obtained results is presented in Table 2, where P_u is the maximum load per connector, s_u is the corresponding slip, K_o is the slip modulus of the connection calculated as the initial slope of the load-slip curve and D is the ductility of the connection.

Table 2: Experimental data from push-out tests

Specimen	P_u (kN)	s_u (mm)	K_o (N/mm)	D
PO ₁	2.23	10.6	428	5.0
PO ₂	2.34	13.0	325	4.8
PO ₃	2.28	12.0	297	5.2
AVERAGE	2.29	11.9	350	5.0

3.2 Results of flexural tests

For all specimens comprising CFS sheeting (namely specimens F₁ and F₃), failure was eventually triggered due to local buckling developing between the point loads delineating the constant-moment section – a typical example is shown in Figure 8.

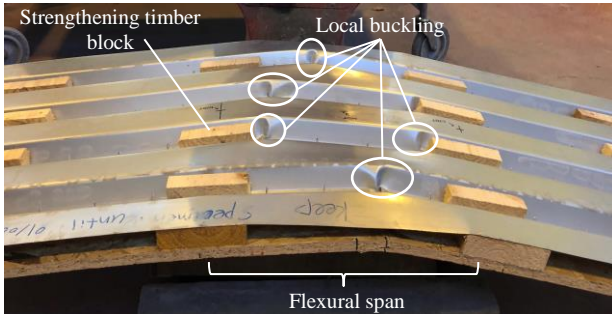


Figure 8: Development of local buckling at peak load of a typical specimen (figure shows specimen underside)

In Figure 9, the moment M carried by each flexural specimen is plotted against the corresponding midspan deflection δ_{mid} . It can be observed that both the deformation and load carrying capacity of the composite panel (specimens F₃) were substantially enhanced compared to the bare CFS panel (specimen F₁) due to the connection between the CFS sheeting and OSB boards.

The initial peak observed in the moment-deflection response of specimen F₃ is attributed to the initiation of local buckling within the CFS sheeting. However, as also observed in [3], due to the partial composite action present within the system, redistribution of internal forces permitted the system to carry more load and, eventually, a substantially higher moment resistance.

The obtained experimental results are summarised in Table 3 where M_u is the ultimate moment capacity of each specimen, s_h is the recorded horizontal slip at ultimate load (averaged from measurements taken from both panel ends) and EI is the flexural stiffness

calculated based on the slope of the load-midspan deflection curve up to 20% of the peak load.

Table 3: Experimental results of flexural tests

Specimen	M_u (kNm)	s_h (mm)	EI ($10^4 \times \text{Nm}^2$)
F ₁	2.51	NA	3.39
F ₂	0.83	NA	0.21
F ₃	4.62	4.6	4.13

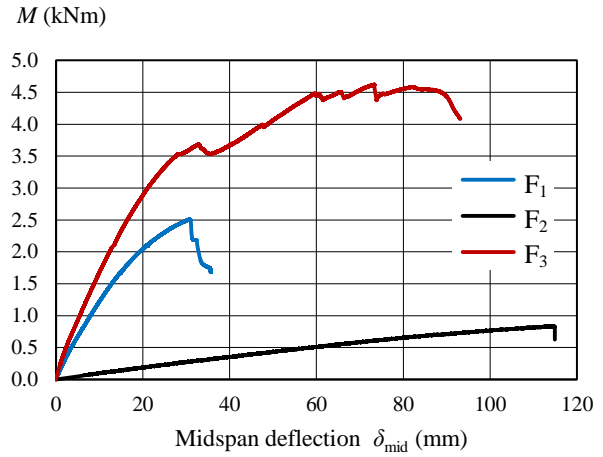


Figure 9: Moment-midspan deflection behaviour of flexural specimens

In order to more clearly exhibit the benefits derived due to the developed composite behaviour, the moment capacities M_u and flexural stiffnesses EI of all specimens, normalised by the capacities $M_{u,NC}$ and stiffnesses $(EI)_{NC}$ of the equivalent non-composite (NC) system are presented in Figure 10. For the determination of the capacity and stiffness of the non-composite system NC, it was assumed that the relative slip of the OSB and CFS panels occurring at their interface was free to develop due to the complete lack of connection between them. Hence, $(EI)_{NC}$ was calculated by summing the flexural stiffnesses of the bare CFS and OSB panels (EI_{F1} and EI_{F2} , respectively) while $M_{u,NC}$ was determined as the sum of the ultimate capacity of the CFS panel $M_{u,F1}$ and the moment attained by the OSB panel at a midspan deflection corresponding to $M_{u,F1}$ (namely $M_{F2} = 0.28$ kNm). Hence, as shown by the bar charts presented in Figure 10, increases of up to 50% in strength and 8% in stiffness have been achieved, due to the mobilisation of composite action within the examined systems.

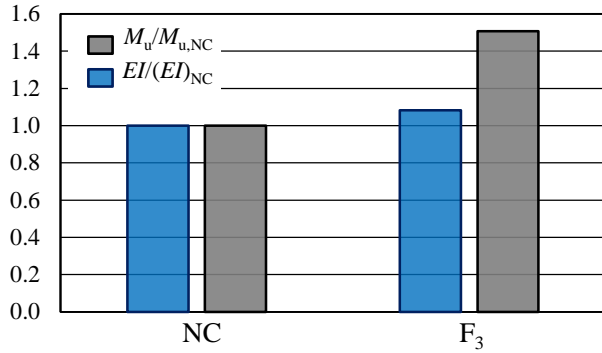


Figure 10: Improvements in terms of moment resistance and flexural stiffness due to mobilisation of composite action

3.3 Discussion

In composite construction, the basic requirement for equally spaced shear connectors is sufficient deformation capacity in order for all of them to be approximately equally loaded under flexure, allowing for sufficient redistribution of the longitudinal force at the shear interface [9,10]. Hence, the ductility of the shear connection employed within a composite system is substantial as it shows its ability to undergo plastic deformations without a significant reduction in strength, allowing for redistribution within the system and preventing premature failure of the connection.

The results of the push-out tests showed that the connection between CFS and OSB using self-tapping screws provides ductility and, as shown in Figure 6, an ultimate slip at their interface ranging from 15 to 20 mm. This ultimate deformation is much larger than the equivalent peak slip recorded in the flexural tests (4.6 mm) and, therefore, the connection is capable of transferring load effectively between the two materials up to failure. Thus, the brittle failure modes of splitting in the OSB and local buckling in the CFS (shown in Figures 11 and 12, respectively) are restrained in the composite system, and, although they both occur (as shown in Figure 13), they do not lead to failure of the composite system. Overall, the proposed composite panel shows a good elastic-plastic response, which suits current Eurocode design methods for the Ultimate Limit State.



Figure 11: Brittle failure of OSB panel (specimen F₂)

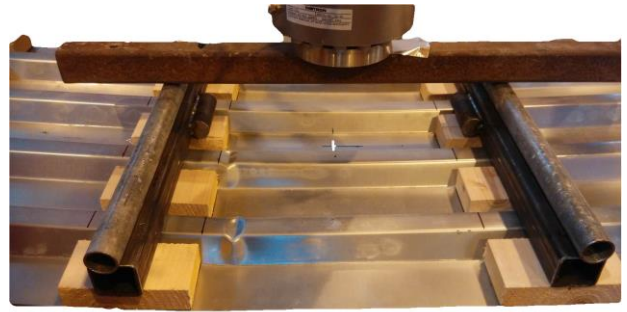


Figure 12: Local buckling triggering failure of bare CFS panel (specimen F₁)



Figure 13: Deformed shape of composite panel (specimen F₃)

Building on these promising results, ongoing research comprises further physical tests where additional key parameters will be explored and more data generated. Numerical models, capable of replicating the examined systems, will also be developed. This work will permit simple design rules to be established, allowing the practical design and application of the proposed system in countries in real need of rapid construction technology innovation.

4 CONCLUSIONS

An experimental programme has been carried out to investigate composite behaviour arising within panels comprising cold-formed steel panels and oriented strand boards, connected with self-drilling screws.

A series of push-out and flexural tests were performed to explore the structural behaviour of the proposed system as well as of its constituent components. It was found that the mobilisation of composite action through the use of a substantial shear connection (i.e. self-drilling screws at 100 mm spacings) is feasible, leading to significant gains in terms of flexural stiffness and moment capacity for the examined systems (8% and 50%, respectively), improving their performance both under serviceability and ultimate limit states. Future research includes further physical tests in order to broaden the pool of experimental data, the development of finite element models which, after validation, will allow the influence of further key parameters to be examined and, ultimately, the establishment of simple rules that would enhance the design of the proposed panels and would hence promote their use in practice.

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